

## **Final Report**

**Project Title:** Coupled Orbit and Attitude Motion of Spacecraft Formations

**Contract Number:** F49620-01-1-0106

**Submitted:** April 20, 2005

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## Overview of Project Activities

During this project, I continued to develop the spacecraft dynamics and control research capabilities here at Virginia Tech, to expand the opportunities for students to interact with Air Force, NASA, and industry engineers, and to leverage AFOSR funding.

The primary facility involved in the project research is the Space Systems Simulation Laboratory, which consolidates several space-related experimental efforts, including a linear air track facility, the Distributed Spacecraft Attitude Control System Simulator, a magnetic bearing system, and a control moment gyro system developed with funding from Honeywell, Inc. This laboratory is being used in experimental studies of coupled attitude and orbital motion, the effects of base motion on magnetic bearings, and various problems associated with momentum wheels and control moment gyros (CMGs).

During this project, I graduated 11 M.S. students and three Ph.D. students, and between the end of the project and this report, I graduated two additional M.S. students and three additional Ph.D. students. Eleven journal articles were published or accepted for publication. Three journal articles are out for review, and several are in preparation. Twenty-seven conference papers were presented at several conferences. Details of these papers are included below.

I chaired the AIAA Astrodynamics Technical Committee from 2002–2004. This TC oversees the development of astrodynamics standards, organizes two conferences per year, and is involved with several other space dynamics-related activities. I nominated several professional colleagues for advancement to Associate Fellow of AIAA and one for advancement to Fellow. I also became the Book Review Editor for the *AIAA Journal of Guidance, Control and Dynamics*, an Associate Editor of the *AAS Journal of the Astronautical Sciences*, and an Associate Editor for *Celestial Mechanics and Dynamical Astronomy*.

I chaired the Department of Aerospace and Ocean Engineering's Faculty Search Committee, which resulted in the hiring of three excellent new professors, including two dynamics and control experts:

**Hanspeter Schaub** comes to us from Sandia Labs, and he earned his Ph.D. in Aerospace Engineering working with Professor John Junkins at Texas A&M University.

**Naira Hovakimyan** joins us from Georgia Tech, where she worked with Tony Calise's group in adaptive control applications. She earned her Ph.D. in Physics and Mathematics at the Institute of Applied Mathematics of Russian Academy of Sciences.

## Personnel Supported

Fourteen graduate students and several undergraduate students have participated in spacecraft dynamics and control projects. The graduate students' names, accomplishments, and current status are provided below.

**Mizuho Aoyagi** completed her M.S. degree with a project on interfacing Matlab into real-time flight control algorithms. She is currently with Jsat Corp in Japan.

**Matthew Berry** developed new numerical integration techniques under the sponsorship of the Naval Research Laboratory, and is also working with the software development team for our University Nanosatellite Project. He presented several conference papers and has one journal

article in print, and completed his PhD dissertation in 2004. He currently works for Analytical Graphics, Inc. in Pennsylvania.

**Victor Collazo-Perez** identified interesting approximate invariance principles in the minimum-time orbital phasing maneuver problem. These results were published in the *AIAA Journal of Guidance, Control, and Dynamics*. Mr. Collazo-Perez now works Analex Corp in Brook Park, Ohio.

**2Lt Michael Edmonston**, USAF, completed his M.S. in August 2001, with sponsorship of the Air Force Institute of Technology's Civilian Institution program. His research project investigated the distribution of charged particles likely to be encountered by spacecraft flying in formation using Pulsed Plasma Thrusters. He is currently in the Undergraduate Pilot Training program.

**Christopher Karlgaard** completed his M.S. thesis in July 2001 under the supervision of Professor Fred Lutze. His research focused on higher-order solutions to the relative motion problem. He is currently with Analytical Mechanics Associates in Hampton, Virginia.

**Mischa Kim** investigated the nonlinear control of rotating tethered systems with funding from NASA Goddard Space Flight Center, as well as developed new results for low-thrust orbit transfer. He presented three conference papers and has had two journal articles accepted for publication, with one in review and two additional journal articles in preparation. He defended his PhD dissertation in 2005 and has accepted a position on the faculty at the Embry-Riddle Aeronautical University in Arizona. While a graduate student, he received the AAS John V. Breakwell Student Travel Award, two Society of Satellite Professionals International Awards, and the Paul E. Torgersen Graduate Research Excellence Award.

**Scott Lennox** completed his M.S. degree while working on the systems engineering for our University Nanosatellite Project, as well as for the Distributed Spacecraft Attitude Control System Simulator. He defended his thesis in 2004 and currently works for a.i.-solutions, inc., in Maryland.

**Kristin Makovec** completed her M.S. in July 2001. She developed a novel nonlinear control strategy for attitude control using magnetic torque coils. Her algorithms were integrated into the attitude determination and control flight software for our University Nanosatellite Project. She is currently with the Flight Dynamics Center at NASA Goddard Space Flight Center.

**Bo Naasz** completed his M.S. in May 2001. He developed a novel nonlinear orbit control strategy using orbital element feedback. His algorithms were integrated into the flight software for our University Nanosatellite Project, and are currently being integrated into the flight software for our spacecraft simulators. He is currently with the Flight Dynamics Center at NASA Goddard Space Flight Center. He has presented two conference papers and submitted one journal article.

**Marcus Pressl** worked on developing, building, and testing hardware for the University Nanosatellite Project, the Distributed Spacecraft Attitude Control System Simulator, and the Magnetic Bearing Base Motion Effects Testbed. He completed his M.S. thesis on *Analysis of the Internal Torques in Rotating Gyrostats* in 2003, and currently works for AeroAstro, Inc. in Virginia.

**Major Ralph Sandfry**, USAF, completed his Ph.D. in July 2001, with sponsorship of the U.S. Air Force Academy through the Air Force Institute of Technology's Civilian Institution program. His research project investigated the relative equilibria of a gyrostatt with flexible component. He is currently on the faculty at the U.S. Air Force Academy at Colorado Springs, Colorado.

rado. He received the University Outstanding Dissertation Award for his work. In addition to several conference papers, two journal articles were published and one is in review.

**Jana Schwartz** was an NSF Fellow, an Amelia Earhart Scholar, and a NASA Graduate Student Research Program Fellow. She was the lead student in developing the Distributed Spacecraft Attitude Control System Simulator, and related projects in the Space Systems Simulation Laboratory. She presented several conference papers and has one published journal article. She defended her dissertation in 2004 and is currently with Draper Labs in Massachusetts.

**Eugene Skelton** completed an M.S. thesis on "Mixed Control Moment Gyro and Momentum Wheel Attitude Control Strategies," which was funded by Honeywell, Inc. He presented one conference paper, and is currently working for Lockheed-Martin on the attitude control system for the Hubble Space Telescope.

**Andrew Turner** completed his M.S. thesis in summer 2003 as a Virginia Space Grant Fellow. He was the software lead for the Nanosatellite project, and developed an open-source framework for spacecraft simulation. He works for Realtime Technologies, Inc., in Royal Oak, Michigan. Mr. Turner has presented two conference papers.

**Matthew VanDyke** worked on techniques for estimating the attitude of low-earth orbit satellites, and on software development. He defended his M.S. thesis in 2004 and currently works for Orbital Sciences Corp. He presented two conference papers and has one journal article in review.

## **Publications (\* indicates student; conference papers are listed under Interactions)**

### **Journal articles accepted or published:**

1. M. Kim and C. D. Hall, "Symmetries in the Optimal Control of Solar Sail Spacecraft," *Celestial Mechanics and Dynamical Astronomy* (to appear)
2. M. Kim and C. D. Hall, "Control of a Rotating Variable-Length Tethered System," *Journal of Guidance, Control and Dynamics*, Vol. 27, No. 5, 2004, pp. 849-858
3. C. D. Hall and J. A. Beck, "Hamiltonian Mechanics and Relative Equilibria of Orbiting Gyrostats," *Journal of the Astronautical Sciences* (to appear)
4. J. L. Schwartz\*, M. A. Peck, and C. D. Hall, "Historical Review of Air-Bearing Spacecraft Simulators," *Journal of Guidance, Control and Dynamics*, Vol. 26, No. 4, 2003, pp. 513-522
5. R. A. Sandfry\* and C. D. Hall, "Steady Spins and Spinup Dynamics of Nearly Axisymmetric Dual-Spin Satellites with Damping," *Journal of Spacecraft and Rockets*, 2004, Vol. 41, No. 6, pp. 948-955
6. R. A. Sandfry\* and C. D. Hall, "Relative Equilibria of a Prolate Gyrostat with a Discrete Damper," *Journal of the Astronautical Sciences*, Vol. 50, No. 4, 2003, pp. 367-387
7. C. D. Hall and V. Collazo Perez\*, "Minimum-Time Orbital Phasing Maneuvers," *Journal of Guidance, Control, and Dynamics*, Vol. 26, No. 6, 2003, pp. 934-941
8. C. D. Hall, P. Tsiotras, and H. Shen\*, "Tracking Rigid Body Motion Using Thrusters and Momentum Wheels," *Journal of the Astronautical Sciences*, Vol. 50, No. 3, 2002, pp. 311-323
9. K. A. Ford\* and C. D. Hall, "Flexible Spacecraft Reorientations Using Gimballed Momentum Wheels," *Journal of the Astronautical Sciences*, Vol. 49, No. 3, 2001, pp. 421-441

10. P. Tsiotras, H. Shen\*, and C. D. Hall, "Satellite Attitude Control and Power Tracking with Momentum Wheels," *Journal of Guidance, Control, and Dynamics*, Vol. 24, No. 1, 2001, pp. 23-34
11. S. P. Hughes\* and C. D. Hall, "Optimal Configurations of Rotating Spacecraft Formations," *Journal of the Astronautical Sciences*, Vol. 48, Nos. 2-3, 2000, pp. 225-247

**Journal articles in review:**

12. R. A. Sandfry\* and C. D. Hall, "Bifurcations of Relative Equilibria of an Oblate Gyrostat with a Discrete Damper," *Nonlinear Dynamics*
13. M. Kim\* and C. D. Hall, "Dynamics and Control of Tethered Satellite Systems for NASA's SPECS Mission," *Journal of Spacecraft and Rockets*
14. M. C. VanDyke\* and C. D. Hall, "Decentralized Coordinated Attitude Control of a Formation of Spacecraft," *Journal of Guidance, Control and Dynamics*

**Theses and dissertations:**

1. Matthew M. Berry, *A Variable-Step Double-Integration Multi-Step Integrator*, Ph.D., May 2004. Currently with Analytical Graphics, Incorporated, Malvern, Pennsylvania
2. Michael Edmonston, "A Numerical Model for the Density of Expelled Teflon Ions at Large Distances from a Pulsed Plasma Thruster," M.S. in Aerospace Engineering, August 2001.
3. Mischa Kim, *Periodic Spacecraft Orbits for Future Space-based Deep Space Observations*, *Diplomarbeit*, Technical University of Vienna, Austria, 2001
4. Mischa Kim, *Continuous Low-Thrust Trajectory Optimization: Techniques and Applications*, Ph.D., May 2005. Has accepted position on faculty at Embry-Riddle Aeronautical University, Prescott, Arizona. *Note:* This student was a College of Engineering Paul E. Torgersen Research Award Winner
5. Scott E. Lennox, *Coupled Attitude and Orbital Control System Using Spacecraft Simulators*, M.S., July 2004. Currently Aerospace Systems Engineer, a.i.-Solutions, Lanham, Maryland
6. Kristin L. Makovec, *A Nonlinear Magnetic Controller for Three-Axis Stability of Nanosatellites*, M.S., July 2001. Currently with the Flight Dynamics Center at NASA Goddard Space Flight Center, Greenbelt, Maryland.
7. Bo J. Naasz, *Classical Element Feedback Control for Spacecraft Orbital Maneuvers*, M.S., June 2002. Currently Flight Dynamics Engineer, NASA Goddard Space Flight Center, Greenbelt, Maryland
8. Marcus C. Pressl, *Internal Torques and Forces in Gyrostats with Magnetically Suspended Rotors*, M.S., December 2003. Currently Engineer, AeroAstro Corp., Ashburn, Virginia
9. Ralph A. Sandfry, *Equilibria of a Gyrostat with a Discrete Damper*, Ph.D., July 2001. Currently Assistant Professor, Department of Astronautics, U.S. Air Force Academy, Colorado Springs, Colorado. *Note:* This dissertation was selected as the University Outstanding Dissertation for 2001.

10. Jana L. Schwartz, *The Distributed Spacecraft Attitude Control System Simulator: From Design Concept to Decentralized Control*, Ph.D., July 2004. National Science Foundation Fellow. Currently Senior Member Technical Staff, Draper Laboratory, Cambridge, Massachusetts
11. C. Eugene Skelton II, *Mixed Control Moment Gyro and Momentum Wheel Attitude Control Strategies*, M.S., November 2003. Currently Pointing Control Subsystem Engineer, Lockheed-Martin Technical Operations, Greenbelt, Maryland
12. Craig L. Stevens, *Design, Analysis, Fabrication, and Testing of a Nanosatellite Structure*, M.S., June 2002. Currently Structural Test Engineer, NASA Goddard Space Flight Center, Greenbelt, Maryland
13. Andrew J. Turner, *An Open-Source, Extensible Spacecraft Simulation and Modeling Environment Framework*, M. S., July 2003. Currently Engineer, Real Time Technologies, Inc., Royal Oak, Michigan
14. Matthew C. VanDyke, *Decentralized Coordinated Attitude Control of a Formation of Spacecraft*, M.S., May 2004. Virginia Space Grant Fellow. Currently Attitude Control Systems Engineer, Orbital Sciences Corp., Dulles, Virginia

## Interactions/Transitions

Participation/presentations at meetings, conferences, seminars, etc.

(\* indicates student, underline indicates presenter)

- **IEEE CCA/CACSD Joint - Control Applications/ Computer Aided Control Systems Design Conference, September 2000, Anchorage, Alaska**  
M. E. Kasarda, J. Clements\*, A. L. Wicks, C. D. Hall, and R. G. Kirk, "Effect of Sinusoidal Base Motion on a Magnetic Bearing"
- **AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, July 8–11, 2001, Salt Lake City, Utah**  
F. S. Gulczinski III, J. H. Schilling, C. D. Hall, and J. R. Woodward\*, "Powersail High Power Propulsion System Design Study"
- **American Institute of Aeronautics and Astronautics/American Astronautical Society Astrodynamics Specialist Conference, August, 2001, Quebec City, Quebec**  
C. D. Hall and M. Kim\*, "Lyapunov and Halo Orbits about  $L_2$ "  
K. L. Makovec\*, A. J. Turner\*, and C. D. Hall, "Design and Implementation of a Nanosatellite Attitude Determination and Control System"  
R. A. Sandfry\* and C. D. Hall, "Relative Equilibria of a Gyrostat with a Discrete Damper"  
C. L. Stevens\*, J. L. Schwartz\*, and C. D. Hall, "Design and System Identification of a Nanosatellite Structure"

**Other participation**

Chair of John V. Breakwell Student Travel Award Subcommittee of the American Astronautical Society Space Flight Mechanics Committee. This award funds student travel to AAS/AIAA conferences for up to 5 students per year.

Elected Chair of AIAA Astrodynamics Technical Committee

General Chair for upcoming Astrodynamics Specialists Conference, August, 2002, Monterey, California

- **American Astronautical Society / American Institute of Aeronautics and Astronautics Space Flight Mechanics Conference, February, 2002, San Antonio, Texas**  
B. D. Naasz\*, C. D. Karlgaard\*, and C. D. Hall, "Application of Several Control Techniques for the Ionospheric Observation Nanosatellite Formation"
  - **5th Annual Workshop on Celestial Mechanics, Albarracín, Spain, June 19 – 21, 2002**  
C. D. Hall and B. D. Naasz\*, "Orbit Element Feedback Control for Spacecraft Trajectories"
  - **Department of Electromechanical Engineering, University of Beira Interior, Covilha, Portugal, Jun 24, 2002**  
Presentation: "Orbit Element Feedback Control for Spacecraft Trajectories"
  - **American Institute of Aeronautics and Astronautics/American Astronautical Society Astrodynamics Specialist Conference, August, 2002, Monterey, California**  
Chair of AIAA Astrodynamics Technical Committee  
Conference General Chair
  - **American Astronautical Society / American Institute of Aeronautics and Astronautics Space Flight Mechanics Conference, February, 2003, Ponce, Puerto Rico**  
Chair of AIAA Astrodynamics Technical Committee
- M. M. Berry\*, B. J. Naasz\*, and C. D. Hall, "Integrated Orbit and Attitude Control for a Nanosatellite with Power Constraints"
- C. D. Hall, "Transitions Between Equilibria for Orbiting Gyrostats"
- C. D. Hall and V. Collazo Perez\*, "Minimum-Time Orbital Phasing Maneuvers"
- M. Kim\* and C. D. Hall, "Control of A Rotating Variable-Length Tethered System"
- J. L. Schwartz\*, M. Peck, and C. D. Hall, "Historical Survey of Spacecraft Simulators"
- **Workshop Participation**  
National Reconnaissance Office/AIAA Workshop on Space Launch Integration, July 24–26, 2001, NRO Headquarters, Chantilly, Virginia. This 3-day workshop focused on planning for improving space launch integration for future NRO missions. The PI was a member of the Analysis team, which produced a report making specific recommendations for research and development thrusts that should be pursued.

- **Department of Aerospace Engineering, University of Illinois, March 31, 2003**  
Seminar Presentation: "Nanosatellite Orbit and Attitude Dynamics and Control"
- **Space-Based Multi-Aperture Research And Technology Study (SMARTS) Workshop, April 29 – May 2, 2003, Albuquerque, New Mexico**  
Presentation: Test Beds for Formation Flying Research
- **The John L. Junkins Astrodynamics Symposium, May 2003, College Station, Texas**  
C. D. Hall and I. M. Ross, "Optimal Attitude Control for Coplanar Orbit Transfers"

Also Chaired session including papers on Spacecraft Simulators, Imaging System Architecture, Space Robots, and Autonomous Inter-spacecraft Rendezvous

- **American Institute of Aeronautics and Astronautics/American Astronautical Society Astrodynamics Specialist Conference, August 2003, Big Sky, Montana**  
Chair of AIAA Astrodynamics Technical Committee  
Chair of session on Trajectory Optimization

C. D. Hall, "When Spacecraft Won't Point," 2003 AAS/AIAA Astrodynamics Specialists Conference, Big Sky, Montana, August 2003

A. J. Turner\* and C. D. Hall, "An Open-Source, Extensible Spacecraft Simulation Software Framework," 2003 AAS/AIAA Astrodynamics Specialists Conference, Big Sky, Montana, August 2003

C. E. Skelton\* and C. D. Hall, "Mixed Control Moment Gyro, Momentum Wheel, and Thruster Control Strategies," 2003 AAS/AIAA Astrodynamics Specialists Conference, Big Sky, Montana, August 2003

J. L. Schwartz\* and C. D. Hall, "Comparison of System Identification Techniques for a Spherical Air-Bearing Spacecraft Simulator," 2003 AAS/AIAA Astrodynamics Specialists Conference, Big Sky, Montana, August 2003

M. M. Berry\* and L. Healy, "Accuracy and Speed Effects of Variable Step Integration for Orbit Determination and Propagation"

- **Department of Mechanical and Aerospace Engineering, University at Buffalo, September 3, 2003**  
Seminar Presentation: "Nanosatellite Orbit and Attitude Dynamics and Control"
- **Department of Mechanical, Aerospace and Nuclear Engineering, Rensselaer Polytechnic Institute, September 5, 2003**  
Seminar Presentation: "Nanosatellite Orbit and Attitude Dynamics and Control"
- **NASA Goddard Space Flight Center Flight Mechanics Symposium, October 2003, Greenbelt, Maryland**  
J. L. Schwartz\* and C. D. Hall, "The Distributed Spacecraft Attitude Control System Simulator: Development, Progress, Plans"



- **American Astronautical Society / American Institute of Aeronautics and Astronautics Space Flight Mechanics Conference, February 2004, Maui, Hawaii**  
J. L. Schwartz\* and C. D. Hall, "System Identification of a Spherical Air-Bearing Spacecraft Simulator"  
M. C. VanDyke\*, J. L. Schwartz\*, and C. D. Hall, "Unscented Kalman Filtering For Spacecraft Attitude State And Parameter Estimation"  
M. Kim\* and C. D. Hall, "Dynamics Of A Triangular Tethered Satellite Formation In The Extended Circular Restricted Three-Body Problem"
- **Conceive-Design-Implement-Operate Conference, United States Naval Academy, June 3, 2004**  
Presentation: "CDIO Activities at Virginia Tech"
- **Sibley School of Mechanical and Aerospace Engineering, Cornell University, March 30, 2004**  
Presentation: "Minimum-Time Continuous-Thrust Orbit Transfers"

**b. Consultative and advisory functions**

- **Air Force Research Laboratory**  
Continued participating in the University Nanosatellite Program, designing and building a nanosatellite (15 kg) that will launch on the shuttle in 2003 or 2004 and will demonstrate formation flying with two other university-built nanosatellites. This effort involved all aspects of space systems engineering, including design, manufacturing, testing, safety, algorithms, and software. The project is in hiatus due to the cessation of Space Shuttle launches.

Continued to participate in flywheel energy storage research with AFRL and NASA Glenn. Received funding from AFRL to investigate base motion effects on magnetic bearings, using the spacecraft simulators that were funded through a DURIP grant as well as other internal and external funding.

Principal contact: Jerry Fausz, AFRL/VSSV, Kirtland AFB, New Mexico.

- **Goddard Space Flight Center, Flight Dynamics Center, Greenbelt, Maryland**  
Continuing to provide technical analysis and support on their formation flying research activities. Several graduate students have been supported and four are currently employed at Goddard as a result of this involvement. A new project involves integrating the Space Systems Simulation Laboratory into Goddard's Formation Flying Test Bed. Additionally, we are working on nonlinear controllers for rotating tethered interferometers, and on studying the structure of minimum-time and minimum-fuel orbital transfers.

Principal contacts: Rich Burns, David Folta, Jesse Leitner, David Quinn

- **Honeywell, Inc., Glendale, Arizona**  
We are working with engineers at Honeywell in two ways: we collaborated on a paper documenting the historical development of spacecraft simulators (*J. Guidance, Control*

*and Dynamics*), and we are investigating the use of mixed control algorithms for spacecraft with both momentum wheels and control moment gyros.

Principal contact: Charles Golson

➤ **Analytical Graphics, Inc., Malvern, Pennsylvania**

This company develops the state-of-the-art Satellite Toolkit software used throughout the industry to model spacecraft dynamics. The PI worked with AGI to establish a donation of multiple software licenses to Virginia Tech and these are being used throughout the space education program here.

Principal contact: Sergei Tanygin

➤ **Air Force Institute of Technology, Wright-Patterson AFB, OH**

AFIT also has a spacecraft simulator, and we have shared information with them regarding the development and application of these simulators.

Principal contact: Major Rich Cobb

## **New Discoveries, Inventions, or Patent Disclosures**

None.

## **Honors/Awards**

### **Other Research Funding**

*Magnetic Field Investigation of Mars*, Virginia Space Grant Consortium, Jul 2004 – Jun 2005

*Distributed Spacecraft Attitude Control System Simulator*, Star Technologies Corporation, Jan 2004 – Dec 2004

*Astrodynamics Algorithms*, Naval Research Laboratory, Dec 2003 – Aug 2004

*A Team Effort in Formation Flying*, NASA Goddard Space Flight Center, May 2003 – Aug 2006

*Investigation of Control Laws for Mixed Momentum Wheel and Control Moment Gyro Systems*, Honeywell, Inc., Sep 2002 – Aug 2003

*COM+ Simulation Architecture with Application to Tethers and Formation Flying*, Star Technologies Corporation, SBIR, Sep 2002 – Aug 2004

*Time-Optimal Control for Formation Establishment and Maneuvering*, NASA Goddard Space Flight Center, Jun 2002 – May 2003

*Experimental Investigation of Distributed Attitude Control for Spacecraft Formation Flying*, Air Force Office of Scientific Research, Defense University Research Infrastructure Program (DURIP), April 2001 – March 2002

*Design Study Proposal: PowerSail High Power Propulsion System*, Air Force Flight Test Center, January 2001 – June 2001

*Additional Work on ION-F: A Space Based Testbed for Distributed Formation Control using the HokieSat Nanosatellite*, April 2001 – March 2002

*Control Effectiveness for Leonardo Orbits*, NASA Goddard Space Flight Center, May 2001 – September 2001

*Extended Funding for 'Virginia Tech Ionospheric Scintillation Measurement Mission'*, Air Force Office of Scientific Research, April 2001 – September 2002

*COM+ Simulation Architecture with Application to Tethers and Formation Flying*, Star Technologies Corporation, SBIR from NASA Goddard Space Flight Center, Sep 2002 – Aug 2004 (pending)

*Time-Optimal Control for Formation Establishment and Maneuvering*, NASA Goddard Space Flight Center, Jun 2002 – May 2004

*Base Motion Effects on Rotating Magnetic Bearings*, Air Force Research Laboratory, Jan 2002 – Dec 2004

*Dynamics and Control of a Tethered Interferometer at L2*, NASA Goddard Space Flight Center, Sep 2001 – Aug 2004

*Platforms for Atmospheric Science Research*, National Institute for Aerospace, Oct 2002 – Sep 2003

*Investigation of Control Laws for Mixed Momentum Wheel and Control Moment Gyros*, Honeywell, Inc., Dec 2002 – Dec 2003

*Semi-Autonomous Spacecraft Docking*, Virginia Space Grant Consortium, May 2003 – May 2004

*Coordinated, Cooperative Relative Attitude Control*, Virginia Space Grant Consortium, Aug 2003 – Aug 2004

*A Team Effort in Formation Flying: Tying Virginia Tech's Distributed Spacecraft Attitude Control System Simulator into NASA Goddard's Formation Flying Testbed*, May 2003 – Aug 2006

### **Other Honors**

Book Review Editor, *Journal of Guidance, Control, and Dynamics*, 2003 – present

Associate Editor, *Journal of the Astronautical Sciences*, 2003 – present

Associate Editor, *Celestial Mechanics and Dynamical Astronomy*, 2004 – present

Associate Editor, *Journal of Guidance, Control, and Dynamics*, Jan 1995 – Dec 2000

Chair, AIAA Astrodynamics Technical Committee, 2002–2004

Dean's Award for Excellence in Teaching, 2001

National Academy of Engineering's Symposium on Frontiers of Engineering, 2001

Secretary, Virginia Tech Chapter of Sigma Xi, 2001-2003

Promoted to Professor, June 2003

## Thompson Chavon F Civ AFRL/AFOSR

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**From:** Streat David A Civ AFRL/AFOSR  
**Sent:** Tuesday, April 26, 2005 9:34 AM  
**To:** Thompson Chavon F Civ AFRL/AFOSR  
**Subject:** FW: final report  
**Attachments:** CDHallFinalReport01-04.pdf

Chavon, here is a final report for you to process. You should print it out and process like you normally would. I would make a folder for all of your electronic reports received, so that if there is a question about one you'll have it for reference.

David A. Streat, Management Analyst  
Air Force Office of Scientific Research  
703-696-8407  
703-696-8450 fax  
david.Streat@afosr.af.mil

"Have a blessed day"

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**From:** Nachman Arje Civ AFRL/AFOSR  
**Sent:** Tuesday, April 26, 2005 8:30 AM  
**To:** Streat David A Civ AFRL/AFOSR  
**Cc:** Chatlynne Chuck J Civ AFRL/AFOSR  
**Subject:** FW: final report

This was on a delinquent list and can now be removed.

Air Force Office of Scientific Research  
ATTN: Dr. Arje Nachman-NM  
875 North Randolph Road  
Ste 325, Room 3112  
Arlington, VA 22203  
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FAX: 703-696-8450

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**From:** Chris Hall [mailto:cdhall@vt.edu]  
**Sent:** Monday, April 25, 2005 11:43 AM  
**To:** Nachman Arje Civ AFRL/AFOSR  
**Subject:** RE: final report

Arje,

Report is attached.

Thank you for the link re the mems gyro.

Chris

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5/2/2005

**From:** Nachman Arje Civ AFRL/AFOSR [mailto:arje.nachman@afosr.af.mil]  
**Sent:** Thursday, March 31, 2005 3:18 PM  
**To:** Chris Hall  
**Subject:** final report

You owe a final on F49620-01-1-0106!

Dr. Arje Nachman  
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